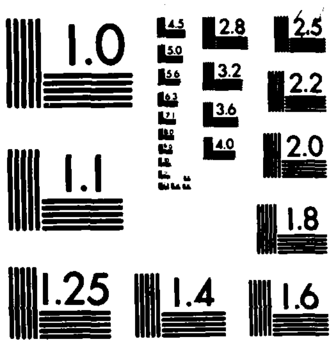
AD-A130 641   AN INVESTIGATION OF CAVITY CYCLING FOR VENTILATED AND NATURAL CAVITIES. (U) PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESEARCH LAB..   1/1

UNCLASSIFIED   D R STINEBRING ET AL. 07 FEB 83   F/G 20/4   NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AN INVESTIGATION OF CAVITY CYCLING FOR VENTILATED AND NATURAL CAVITIES

D. R. Stinebring, M. L. Billet and J. W. Holl

Technical Memorandum
File No. TM 83-13
7 February 1983
Contract No. N00024-79-C-6043

Copy No. 7

The Pennsylvania State University
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16801

Approved for Public Release
Distribution Unlimited

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER TM 83-13	2. GOVT ACCESSION NO. AD-A130 641	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN INVESTIGATION OF CAVITY CYCLING FOR VENTILATED AND NATURAL CAVITIES		5. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) D. R. Stinebring, M. L. Billet & J. W. Holl		8. CONTRACT OR GRANT NUMBER(s) N00024-79-C-6043
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Research Laboratory Post Office Box 30 State College, PA 16801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command, Code NSEA-63R31 Washington, DC 20362		12. REPORT DATE 7 February 1983
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.
Per NAVSEA - July 7, 1983.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

cavitation, frequency, cavity, cycling, ventilated

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The frequency of cavity cycling due to the re-entrant jet was measured for a 45° conical-nosed model having a 1-inch diameter afterbody. Spectral analyses of the output of an internally mounted transducer were performed to determine the cycling frequency. The cavity cycling was also measured from high-speed movies taken of the model cavitation. Data for both natural (vaporous) and ventilated cavities were obtained and compared with data from hydroballistics tank tests of NSWC and previous water tunnel

tests. The cavity cycling frequency presented as a Strouhal number increases with cavitation number. Frequency data, measured by the transducer, for vaporous cavitation were higher than the results for similar ventilated cavities. However, measurements from high-speed movies show close agreement between the cycling frequency for both types of cavitation.

Subject: An Investigation of Cavity Cycling for Ventilated and Natural Cavities

References: See page 9.

Abstract: The frequency of cavity cycling due to the re-entrant jet was measured for a 45° conical-nosed model having a 1-inch diameter afterbody. Spectral analyses of the output of an internally mounted transducer were performed to determine the cycling frequency. The cavity cycling was also measured from high-speed movies taken of the model cavitation. Data for both natural (vaporous) and ventilated cavities were obtained and compared with data from hydroballistics tank tests of NSWC and previous water tunnel tests. The cavity cycling frequency presented as a Strouhal number increases with cavitation number. Frequency data, measured by the transducer, for vaporous cavitation were higher than the results for similar ventilated cavities. However, measurements from high-speed movies show close agreement between the cycling frequency for both types of cavitation.

Acknowledgment: This work was part of a water entry simulation investigation supported by the Naval Sea Systems Command, Code NSEA-63R31.

Table of Contents

List of Tables

List of Figures

7 February 1983
DRS:MLB:JWH:cfb

Nomenclature

D	model diameter
f	cavity cycling frequency
L	cavity length
P_c	cavity pressure
P_∞	free stream static pressure
S	Strouhal number, $\frac{fD}{V_\infty}$
V_∞	free stream velocity
ρ	mass density of water
σ	cavitation number

INTRODUCTION

For a number of years the Applied Research Laboratory, the Pennsylvania State University (ARL/PSU) has been conducting investigations where the cavity-running phase of water entry has been simulated in a water tunnel environment. In the cavity running phase the control surfaces of the vehicle may have only limited contact with the water. The time for the cavity to shorten to the extent that the control surfaces are again effective is of vital interest. Two previous studies, Kim and Holl [1]* and Stinebring and Holl [2], focused on measurement of the entrainment coefficient of ventilated cavities for a wide range of body geometries and flow parameters. This study is an extension of the previous investigations.

It has been shown in Reference 3 that the reentrant jet, formed at the aft end of the cavity, is the main entrainment mechanism. Thus, the frequency with which the reentrant jet strikes the cavity is of interest in evaluation of the air entrainment. This was the primary reason for undertaking this study. It should also be mentioned that an investigation of the cavity dynamics could be useful in understanding other related cavitation effects (besides entrainment), i.e., vibration, noise and cavitation damage. Another study at ARL/PSU, Reference [4], briefly addresses the cavity cycling phenomenon as it pertains to cavitation damage.

A 45° conical-nosed model having a one-inch diameter afterbody was instrumented with an internally mounted piezoelectric transducer. It was expected that the reentrant jet striking the cavity would cause a significant pressure rise that could be measured with the transducer. Spectral analyses were performed on the output of the transducer to determine the frequency of the cavity cycling. Tests were conducted for both vaporous and ventilated cavities over a range of cavitation numbers and velocities. High-speed movies of the cavitation were taken and compared to the spectrum analyzer results. To determine if the boundary layer thickness affects the cycling frequency, a number of tests were conducted with distributed roughness applied to the conical nose. Lastly, the results were compared with the findings of previous investigations in a hydroballistics tank and in water tunnels covering a wide range of model sizes and geometries.

INSTRUMENTATION AND MODEL DESIGN

A schematic of the model designed for this investigation is shown in Figure 1 with details of the nose and transducer mounting presented in Figure 2. The model, 45° conical-nosed body having a one-inch diameter afterbody was strut mounted in the 12-inch diameter water tunnel. The model was equipped with six 0.025-inch diameter holes, around the circumference where the conical nose joins the afterbody, for the introduction of ventilation gas. Ventilation gas was supplied from a single 226 cu. ft. nitrogen

*Numbers in brackets denote documents in list of references.

tank. The flowrate was adjusted using a throttling valve and was measured with a flowmeter. Two 0.065-inch diameter lines carried the gas into the tunnel through the strut. Approximately halfway up the strut, the lines, made of stainless steel hypodermic tubing, emerged and were connected to the model with fittings as shown in Figure 1.

Both average and instantaneous cavity pressures were measured during the tests. The average cavity pressure was measured with a pressure transducer outside the tunnel connected to a pressure tap on the model. The instantaneous cavity pressure was measured with an internally mounted piezoelectric pressure transducer, Type LC71 manufactured by Celesco Transducer Products, Inc. The transducer was mounted with the measurement face installed in a small cavity that was connected to a surface pressure tap as shown in Figure 2. The resonant frequency of the cavity was designed to be much greater than the estimated cavity cycling frequency. A Gilmore Industries zero drive amplifier, amplified the transducer signal for the Spectral Dynamics SD301C real-time spectrum analyzer. The analyzer output was in the form of a chart recording with signal level plotted as a function of frequency. A schematic of the instrumentation employed for the tests is presented in Figure 3.

In order to obtain a better understanding of the transducer/spectrum analyzer results, high speed movies were taken of the cavity behavior. A 16 mm Redlake Hycam high speed movie camera was synchronized with an EG&G Type 501 strobe unit. A framing rate of 2000 frames per second proved satisfactory for observing the gross cavity behavior. Backlighting, where the camera and light source are on opposite sides of the tunnel, provided sufficient detail of the reentrant jet behavior. The frequency with which the reentrant jet would strike the cavity was measured by counting the number of frames between successive cavity cycles.

TEST RESULTS

Typical spectra of the piezoelectric transducer output for ventilated cavities are shown in Figures 4 and 5, and for natural (vaporous) cavities in Figure 6. Upon examination of the plots, two observations can be made. First, the frequency peak for vaporous cavities is more pronounced than for the ventilated cavities. Second, the overall transducer signal decreases (from the noncavitating state) when vaporous cavitation is present. The signal level does not change significantly for ventilated cavities compared with the fully-wetted flow. The reason for each of these observations is not known at this time.

A plot of the cycling frequency, presented as a Strouhal number, versus cavitation index is shown in Figure 7. For both vaporous and ventilated cavitation the Strouhal number increases with cavitation index. It is also apparent that the transducer frequency data for vaporous

cavitation is much higher than that for ventilated cavities. There is a discrepancy though when the cycling frequency measured from the high-speed movies is compared with the transducer output. Cycling frequency measurements from the movies of both vaporous and ventilated cavities showed close agreement with transducer data for the ventilated cavities as shown in the figure. The reason for the lack of agreement with the vaporous cavitation transducer data is not understood at this time. There is a possibility that at reduced pressure the pressure tap leading to the transducer cavity could have been cavitating for the cavity lengths tested. Future tests are planned to help explain the difference.

It can also be seen in Figure 7 that the data for ventilated cavities at the higher cavitation numbers break into two curves. This was unusual since it appeared to be purely random, i.e., not a function of velocity. Upon examination of the original data sheets an explanation was found. It was noted that for test Nos. 38 and above, Table I, the measured cavitation index, using P_c, did not correspond to the recorded dimensionless cavity length (as measured prior to test No. 38). The σ versus L/D data for tests 1 to 37 were in close agreement with results from previous investigations [1], [2]. Further examination revealed that tests before No. 38 were performed prior to December 19, 1978 and those from 38 on were run after January 9, 1979. The possibility existed, noting the time interval between tests, that the gain of one of the transducer amplifiers could accidently have been changed. Transducer No. 8277 (Bell and Howell) was used for measuring the tunnel static pressure and the nozzle pressure drop. The amplifier and power supply for this unit has a gain selector in incremental units of 10, 30, 100 and 300. Switching the gain setting could not have produced the apparent discrepancy. However, the transducer used for measuring cavity pressure (Validyne 15943) had a ten-turn potentiometer for gain control. A small change in the gain on this transducer could account for the difference in cavitation number. This could be the source of the error.

During all tests the length of the cavities were measured, so a reasonably accurate estimate of the cavitation index could be made from the measured cavity length on previous calibrations of σ versus L/D [2]. The corrected cavitation numbers based on cavity length are presented for tests No. 38 and beyond in Table I and Figure 8. All corrected data for ventilated cavities fall close to a single curve.

Some of the data in Table 1 and Figure 8 have the notation, "twin vortex transition". The transition from the reentrant jet to the twin vortex regimes was explained in Reference [2] and takes place when gravitational effects become significant, i.e., long cavity lengths. At the transition between the two regimes there is a change in the appearance of the cavity, Reference [2]. The reason for the measured transducer frequency increase during the transition phase is not known at this time.

As stated previously, surface roughness was applied to the conical nose for observing any changes in cycling frequency. The results in Figure 8 show little effect on the frequency for both natural and ventilated cavities.

A comparison of the results for this study are presented with data from other investigators in Tables II and III and in Figure 9. Included are a range of model sizes from 0.25 to 3.0 inches in diameter, three different flow geometries, and data for both natural and ventilated cavities. The results by Knapp [5] for hemispherical-nosed bodies are in closest agreement with this present investigation. All data show the same trend, i.e., an increase in cycling frequency with cavitation number.

The hydroballistics tank data was taken from transducer output plots, such as the one presented in Figure 10 (Reference [6]). The cycling frequency was measured by counting the number of cycles over a specific time interval. The Strouhal number was calculated using the missile entry velocity and the cycling frequency. Much of the scatter in the data may be due to using the entry velocity instead of the instantaneous velocity (which was not available).

CONCLUSIONS

1. The cavity cycling frequency presented as a Strouhal number increased with cavitation number for all cases studied.

2. The frequency data as measured with the transducer is much higher for vaporous cavitation than for ventilated cavities. However, the frequency measured from high-speed movies of the cavity cycling show close agreement, between both types of cavitation, and with the ventilated cavitation transducer data.

3. A comparison with the results of previous investigators shows the same trend in the data, i.e., the Strouhal number increases with cavitation number. Agreement was good between the results of Knapp [5] for hemispherical-nosed models and this investigation.

REFERENCES

[1] Kim, J. H. and J. W. Holl, "Water Tunnel Simulation Study of the Later Stages of Water Entry of Conical Head Bodies," Applied Research Laboratory, Technical Memorandum 75-177, June 18, 1975.

[2] Stinebring, D. R. and J. W. Holl, "Water Tunnel Simulation Study of the Later Stages of Water Entry of Conical Head Bodies: Phase II - Effect of the Afterbody on Steady State Ventilated Cavities," Applied Research Laboratory, Technical Memorandum 79-206, December 3, 1979.

[3] May, A., "Water Entry and Cavity-Running Behavior of Missiles," Naval Sea Systems Command Hydroballistics Advisory Committee Technical Report 75-2, Section 3, page 32, 1975.

[4] Stinebring, D. R., "Scaling of Cavitation Damage," M.S. Thesis, The Pennsylvania State University, August 1976.

[5] Knapp, R. T., "Recent Investigations of Cavitation and Cavitation Damage," Trans. ASME, 77, pp. 1045-1054, 1955.

[6] Smith, C. W., "Experimental Investigation of the Behavior of Vertical Water-Entry Cavities," Naval Surface Weapons Center, NSWC/WO1 TR 78-135, September 1978.

TABLE I

Tabulation of Data for This Investigation

Test No.	Velocity ft/sec	L/D (Approx.)	σ (Measured)	Frequency Peak Hz	$S = \frac{fD}{V_\infty}$	Comments
1	29.9	2.0	0.268	28	0.078	Ventilated Cavities
2	"	1.5	0.317	36	0.100	Unless Otherwise Stated
3	"	1.0	0.406	63	0.176	
4	"	0.5	0.434	—	—	
5	"	2.5	0.232	23.5	0.065	
6	"	3.0+	0.208	17.5	0.049	
7	"	3.5+	0.213	16	0.045	
8	29.7	0	—	[100Hz]*	—	
9	45.0	2.0	0.244	41	0.076	
10	"	1.5	0.289	50	0.093	
11	"	1.0	0.378	93	0.172	
12	"	0	—	[100Hz]	—	
13	"	0.5	0.426	150	0.278	
14	"	0	—	[500Hz]	—	
15	"	0.75	0.424	132	0.244	
16	"	2.5	0.215	35	0.065	
17	"	3.0	0.186	27.5	0.051	
18	"	3.5	0.165	26.5	0.049	
19	"	4.0	0.159	22.5	0.042	
20	"	4.75	0.159	—	—	
21	"	6.5	0.132	13.5	0.025	
22	49.9	2.0	0.252	44	0.073	
23	"	1.5	0.300	54	0.090	
24	"	1.0	0.387	87	0.145	
25	"	0	—	[100Hz]	—	
26	"	0.75	0.433	120	0.200	
27	"	0	—	[500Hz]	—	
28	"	1.0	0.378	90	0.150	
29	"	1.5	0.307	52	0.087	
30	"	0.5	0.423	187	0.312	
31	"	2.5	0.211	36	0.060	
32	"	3.0	0.197	30	0.050	
33	"	3.5	0.179	27	0.045	
34	"	4.0	0.166	24	0.040	
35	"	5.0	0.143	42.5	0.071	Twin Vortex Regime

*Numbers in brackets are spectra range for background (no cavitation) levels.

TABLE I (Cont'd)

Test No.	Velocity ft/sec	L/D (Approx.)	σ (Measured)	Frequency Peak Hz	$S = \frac{fD}{V_\infty}$	Corrected σ	Comments
36	49.9	6.0	0.129	37	0.062	—	Twin Vortex Transitio
37	"	7.0	0.115	29	0.048	—	"
37a	"	TV	0.106	—	—	—	"
38	45.1	2.2	—	38	0.071	0.224	High Speed Movie
39	45.3	2.9	0.242	32	0.060	0.192	"
40	"	0	—	[500Hz]	—		
41	50.1	0.5	0.536	1140	1.896	0.423	Vaporous Cavitation
42	"	0	—	[2000Hz]	—	—	"
43	"	0.75	0.458	448	0.745	0.433	"
44	"	1.0+	0.390	400	0.665	0.383	"
45	"	1.5	0.327	395	0.657	0.303	"
46	"	2.0	0.245	390	0.649	0.252	"
47	"	1.5	0.259	394	0.654	0.303	"
48	"	0	—	[500Hz]	—	—	"
49	"	0	—	[1000Hz]	—	—	"
50	"	1.5	0.320	74	0.657	0.303	Vaporous, High Speed Movie
51	"	0.5	0.498	190	0.316	0.423	Ventilated Cavities
52	"	0.75	0.465	132	0.220	0.433	"
53	"	0	—	[500Hz]	—	—	"
54	50.4	1.0	0.437	100	0.165	0.383	"
55	45.0	0.5	0.508	170	0.315	0.426	"
56	"	0.75	0.479	117	0.217	0.427	"
57	"	1.0	0.452	100	0.185	0.378	"
58	"	0	—	[500Hz]	—	—	"
59	49.8	1.0	0.366	395	0.661	0.383	Roughened Nose,
60	"	1.75	0.261	395	0.661	0.275	Vaporous Cavitation
61	50.1	0	—	[1000Hz]	—	—	
62	45.2	1.0	0.326	—	—	0.378	Roughened Nose,
63	"	0	—	[500Hz]	—	—	Ventilated
64	"	1.5	0.279	35	0.064	0.289	Cavities
65	"	0	—	[100Hz]	—	—	"
66	"	1.0	0.334	—	—	0.378	"

TABLE II

Comparison of Model Configurations for Four Investigations

Investigator	Model	Facility	Model Diameter Inch	Type of Cavitation
This Investigation	45°, Conical	Water Tunnel	1.0	Ventilated & Vaporous
Knapp [4]	Hemispherical	Water Tunnel	0.5, 1.0, 2.0	Vaporous
Stinebring [5]	0 Caliber Ogive	Water Tunnel	0.25	Vaporous
Smith [6]	45°, Conical	Ballistics Tank	1.0, 3.0	?

TABLE III

Cavity Cycling Data for Three Investigations

	Diameter Inch	Velocity ft/sec	σ	Frequency Hz	$S = \frac{fD}{V_\infty}$
Knapp [4] Hemisphere	0.5	90	0.241	172	0.080
	1.0	"	0.348	200	0.185
	1.0	"	0.263	114	0.105
	2.0	"	0.409	133	0.247
	2.0	"	0.378	111	0.206
	2.0	100	0.326	82	0.137
	2.0	90	0.322	74	0.136
	2.0	77.5	0.334	68	0.147
	2.0	59	0.326	50	0.141
Stinebring [5] 0 Caliber Ogive	0.25	75.5	0.384	172	0.048
	"	75.5	0.337	——	——
	"	75.5	0.342	——	——
	"	75.5	0.386	194	0.054
	"	61.7	0.370	118	0.040
	"	100.0	0.345	153	0.032
	"	75.5	0.490	444	0.122
	"	75.1	0.349	119	0.033
	"	75.5	0.481	443	0.119
	"	49.5	0.365	97	0.041
	"	100.0	0.376	205	0.043
	"	49.5	0.377	122	0.051
Smith [6] 45° Conical Nose	1.0	39.1	0.080	105	0.224
	"	37.6	0.075	93	0.206
	"	41.9	0.075	100	0.199
	"	41.9	0.120	145	0.288
	"	54.2	0.095	110	0.169
	"	86.6	0.060	95	0.091
	"	65.6	0.100	110	0.140
	3.0	131.5	0.075	27	0.051
	"	93.0	0.090	31.5	0.085
	"	43.8	0.100	33	0.188
	"	85.7	0.105	35	0.102

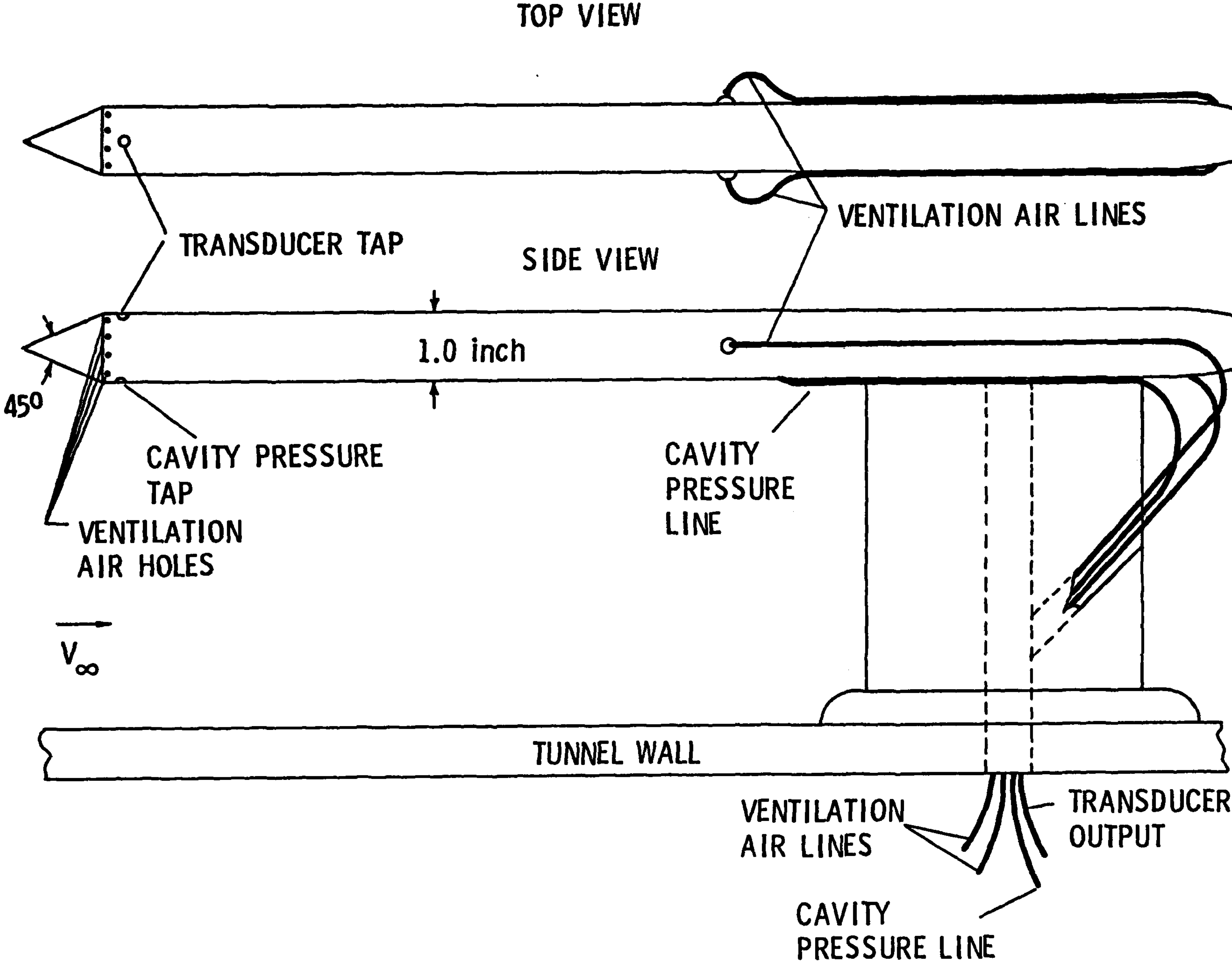


Figure 1. Model Geometry for This Investigation.

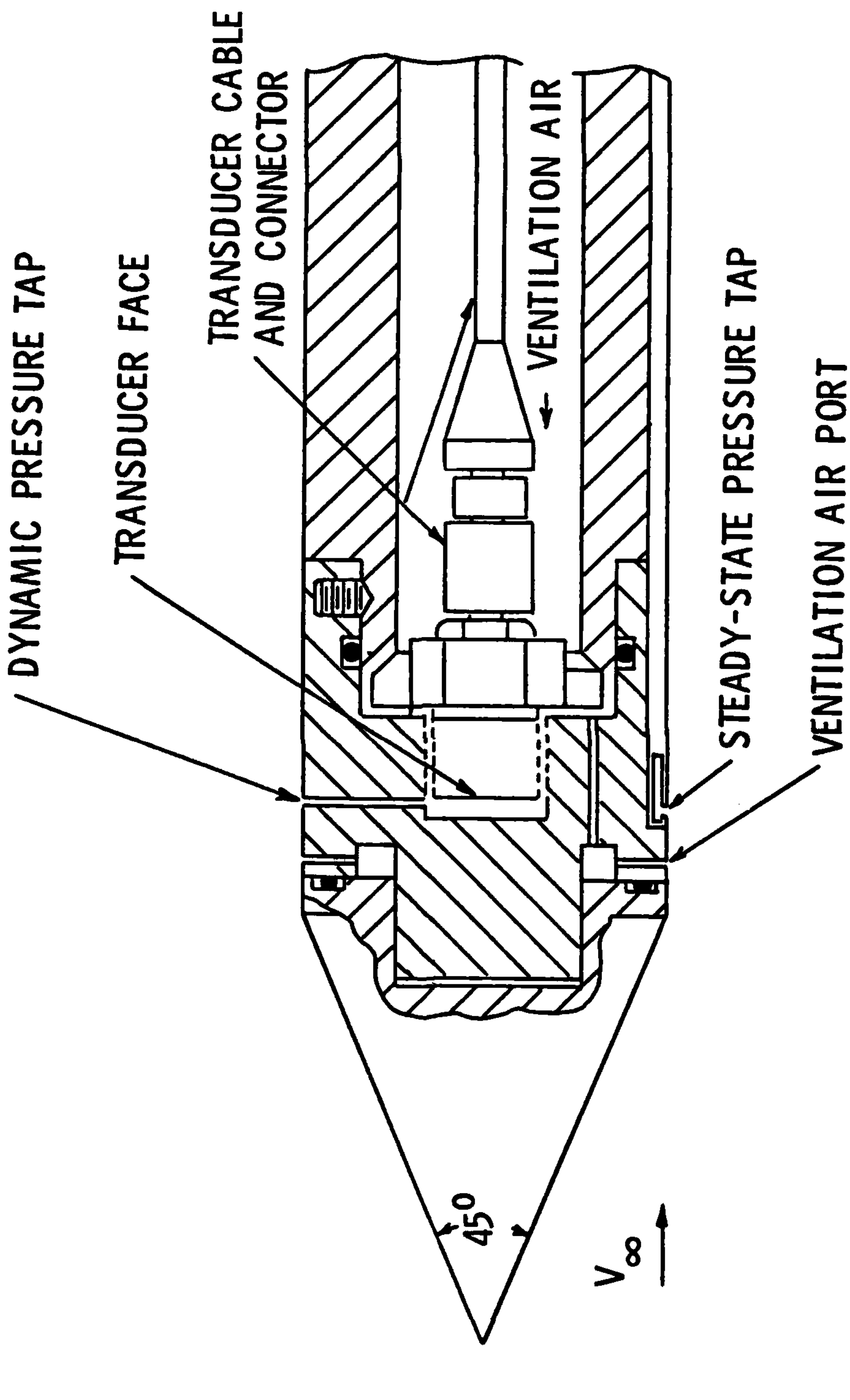


Figure 2. Detail of Forward Section of Model.

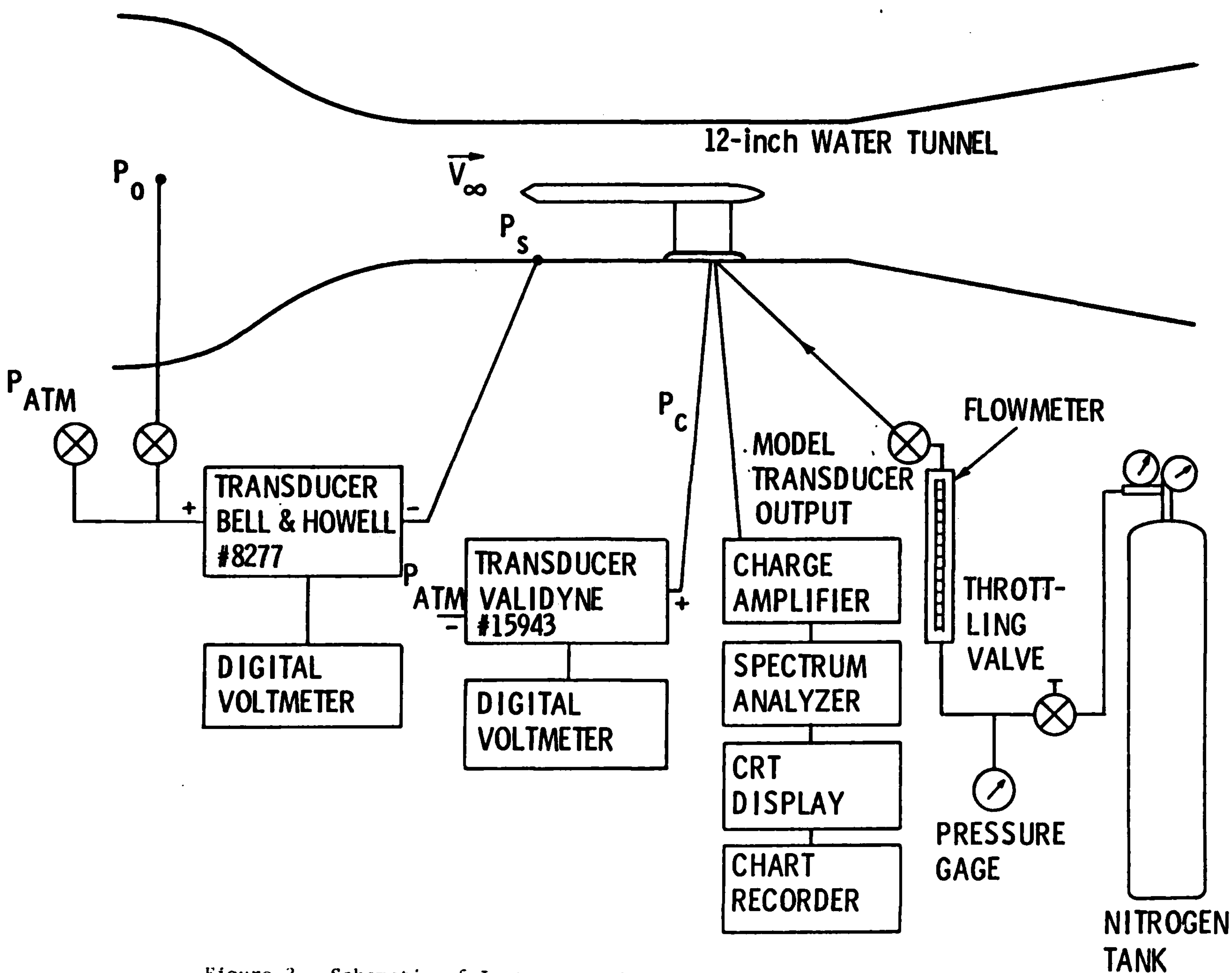


Figure 3. Schematic of Instrumentation for This Investigation.

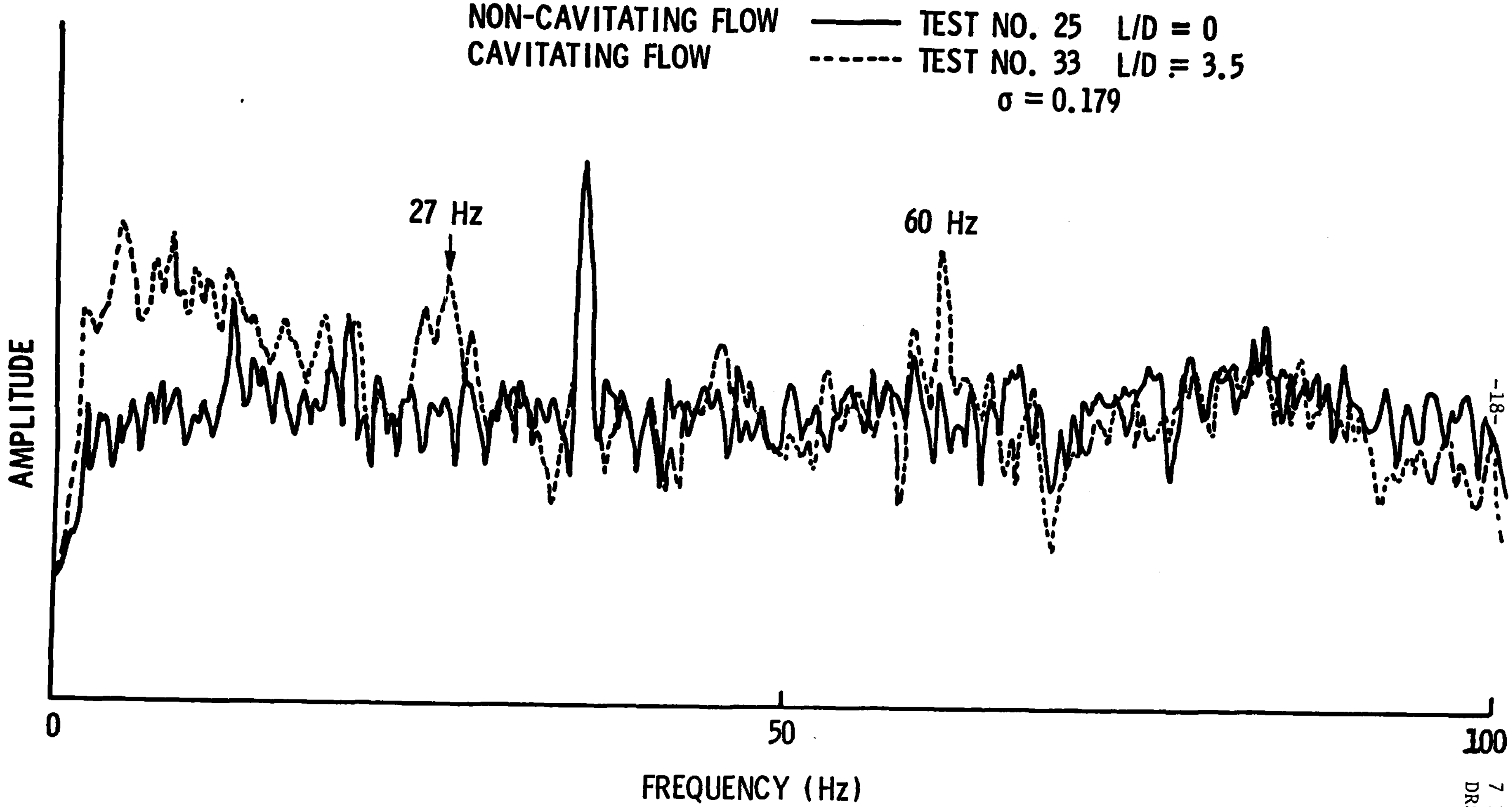


Figure 4. Example of Spectrum Analyzer Output for Ventilated Cavity Tests, Nos. 25 and 33, Frequency Peak at 27 Hz.

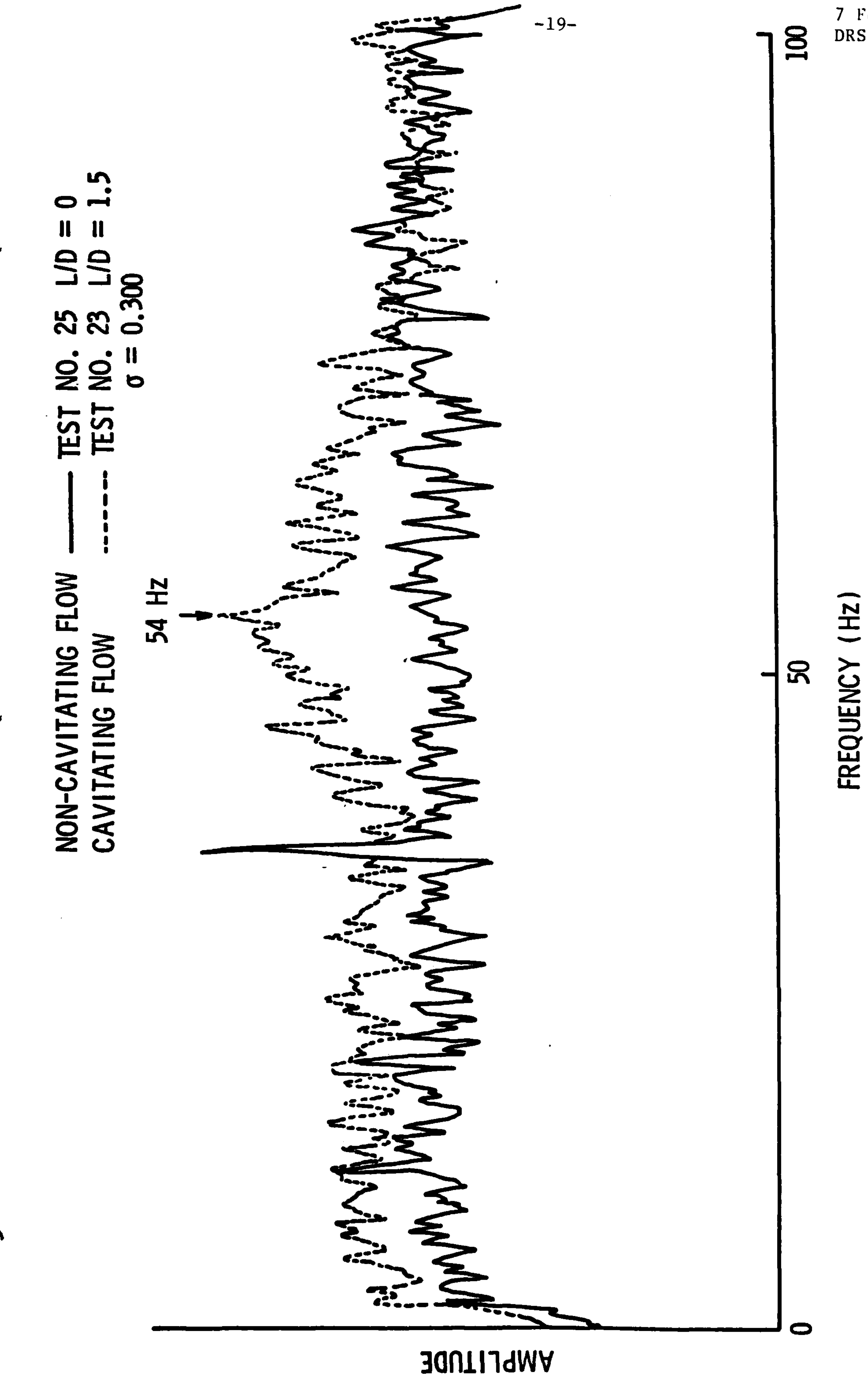


Figure 5. Example of Spectrum Analyzer Output for Ventilated Cavity Tests, Nos. 25 and 23, Frequency Peak at 54 Hz.

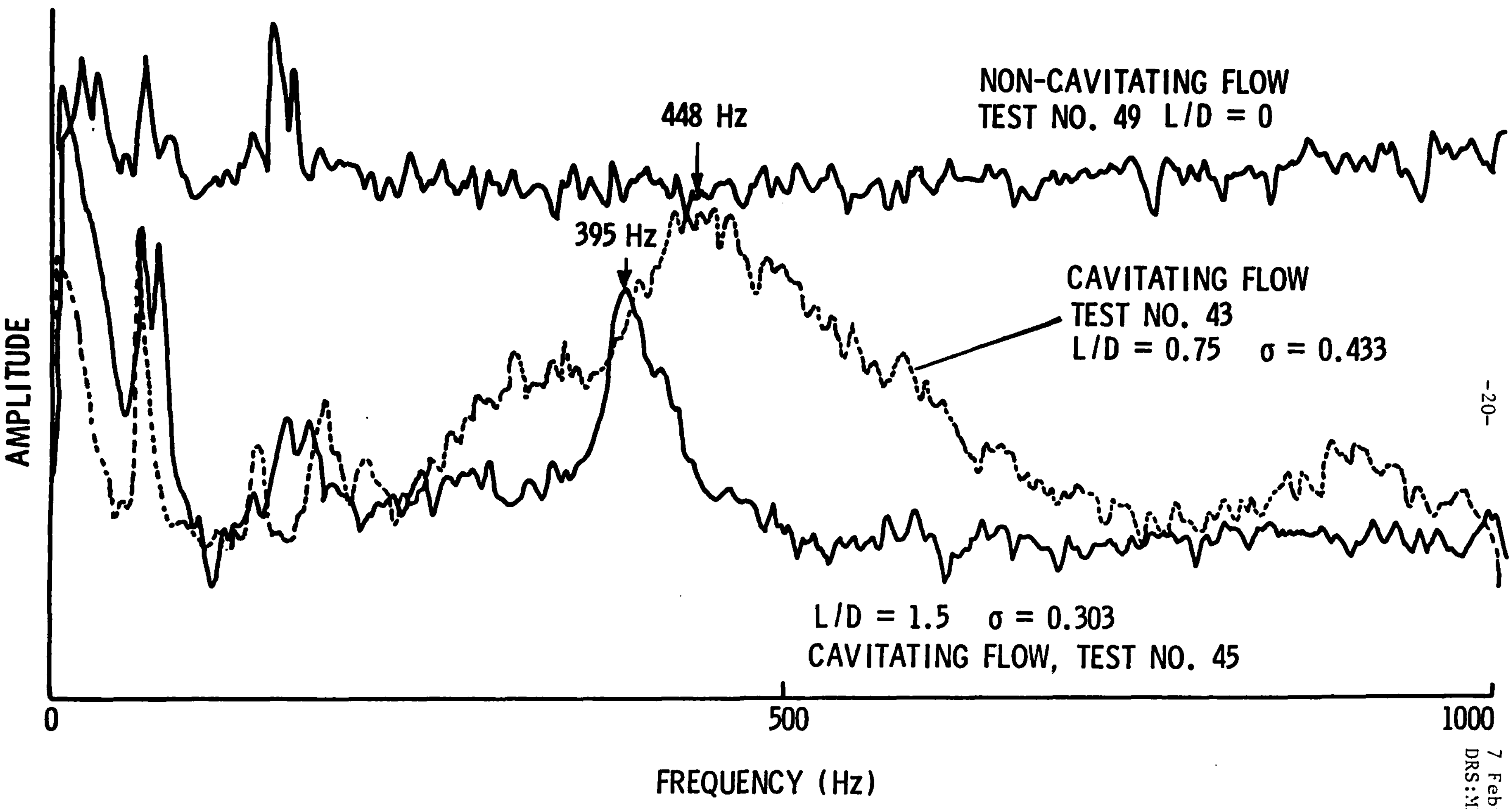


Figure 6. Example of Spectrum Anzlyzer Output for Natural Cavity Tests, Nos. 43, 45 and 49, Frequency Peaks at 395 Hz and 448 Hz.

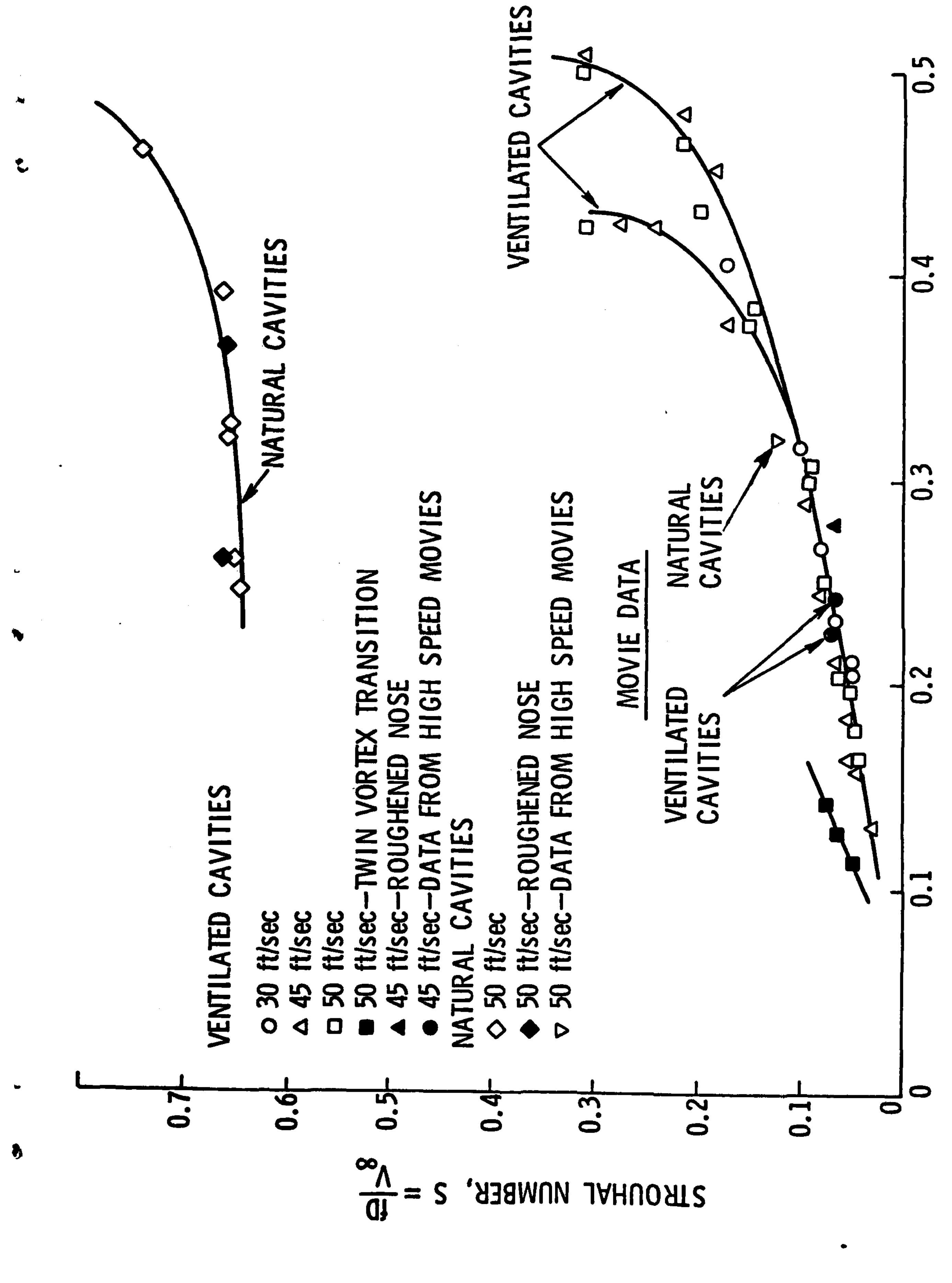


Figure 7. Strouhal Number Versus Cavitation Number for This Investigation--45° Conical-Nosed Body Having a One-Inch Diameter Afterbody.

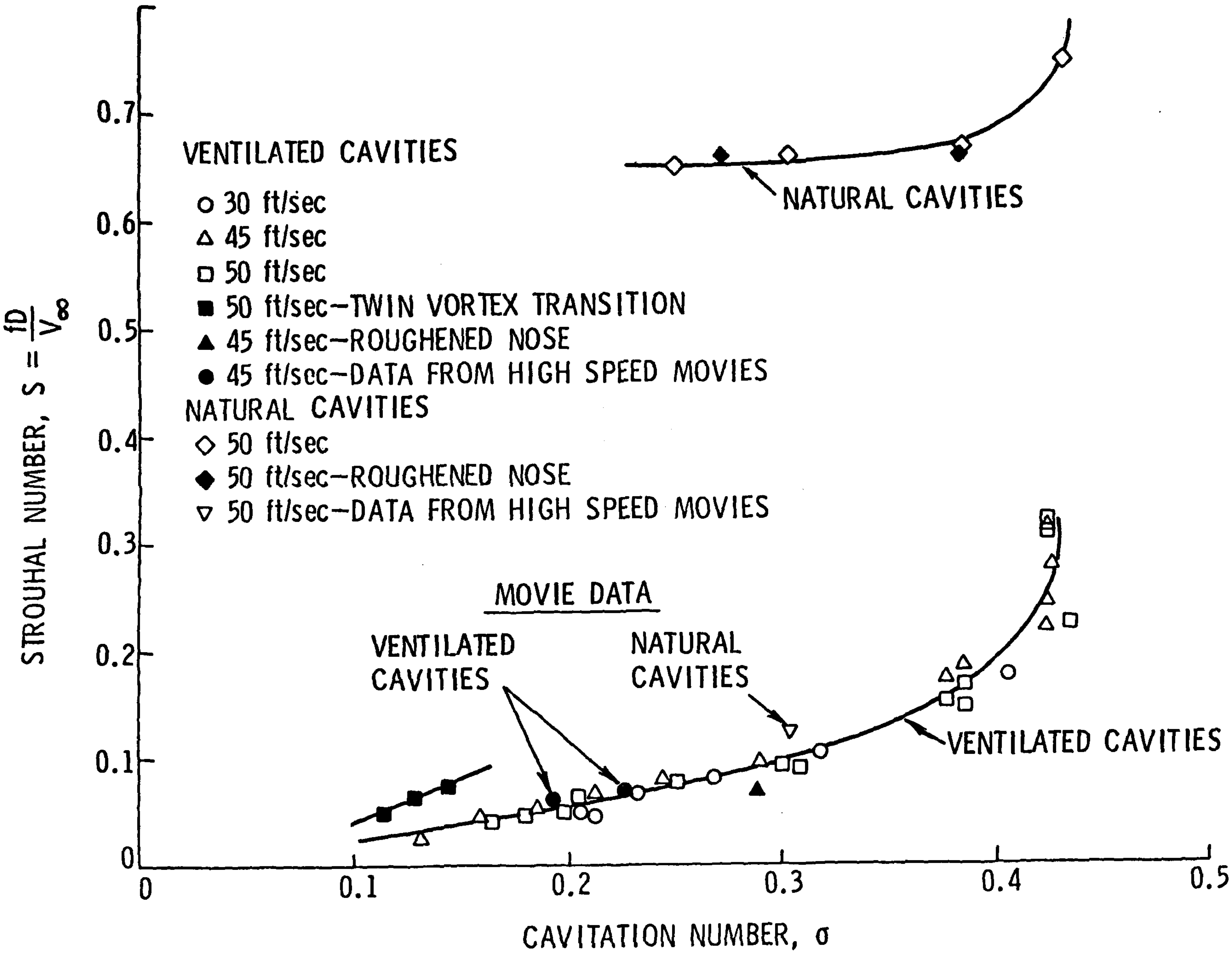


Figure 8. Strouhal Number Versus Cavitation Number for This Investigation--45° Conical-Nosed Body Having a One-Inch Diameter Afterbody--Corrected Cavitation Number.

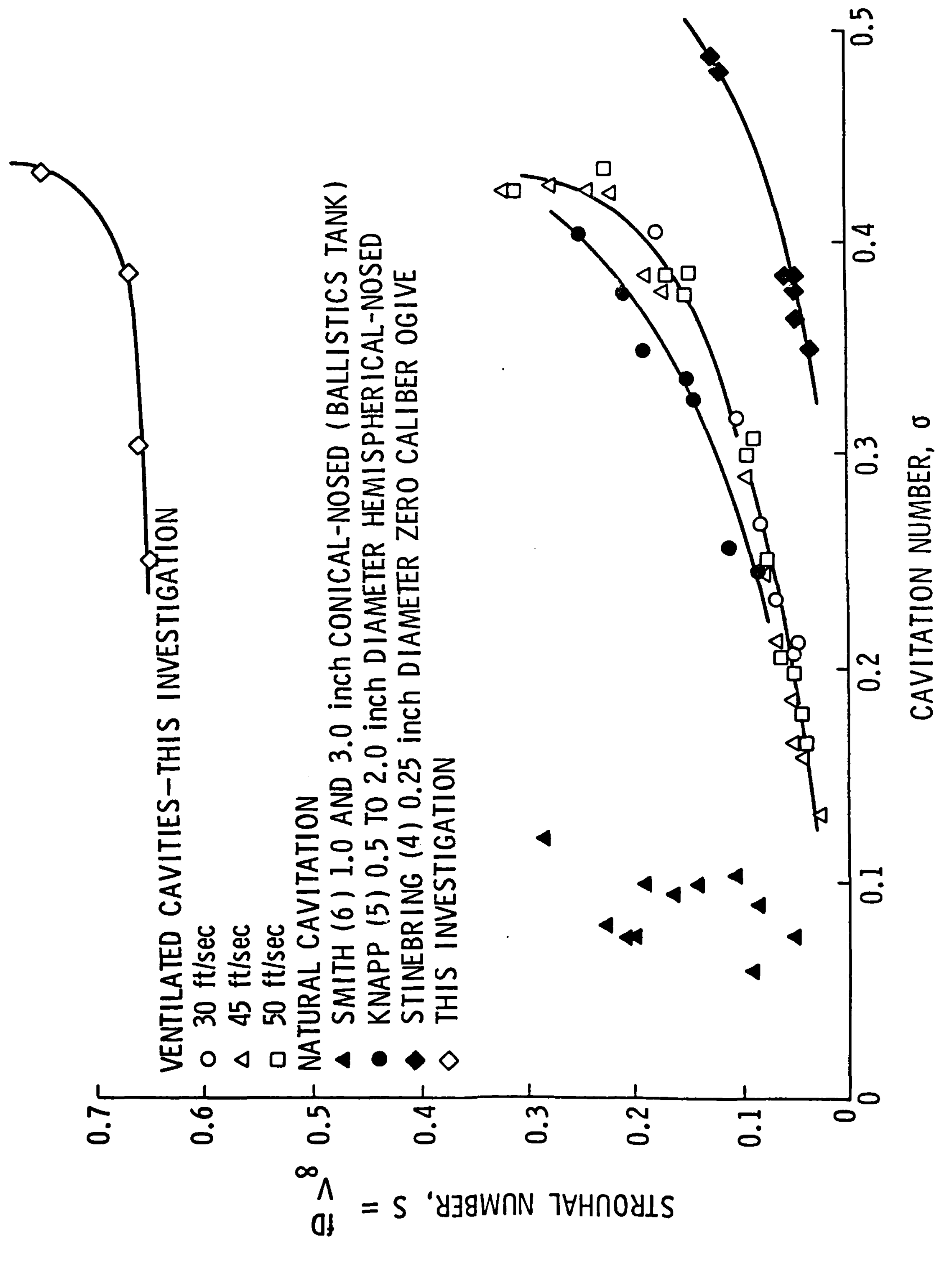


Figure 9. Strouhal Number Versus Cavitation Number--Comparison of Results With Other Investigations.

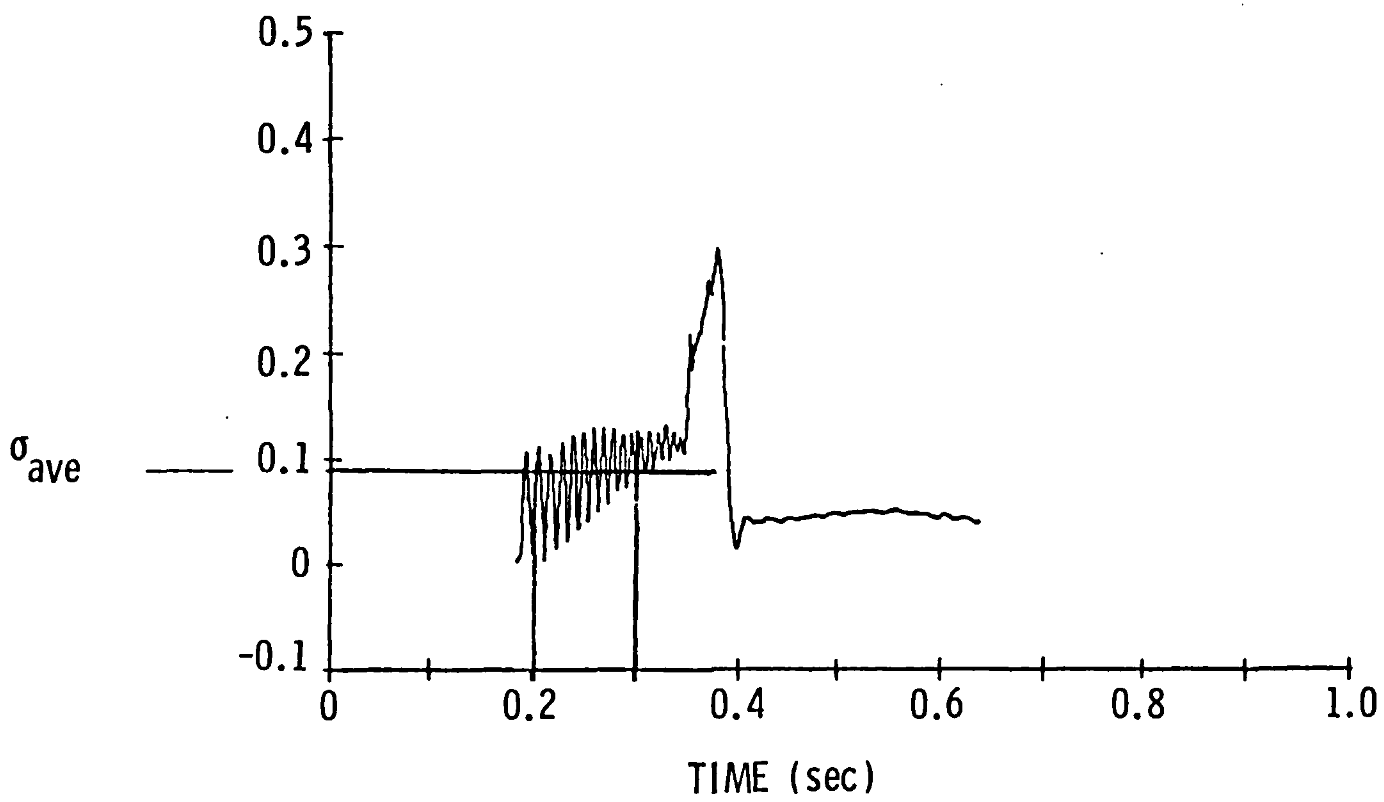


Figure 10. Typical Transducer Output for Ballistics Tank Test at NSWC Reference [6].

Distribution List for UNCLASSIFIED TM 83-13 by D. R. Stinebring, M. L. Billet and J. W. Holl, dated 7 February 1983

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: Library
Code NSEA-09G32
(Copies 1 and 2)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: A. R. Paladino
Code NSEA-55N
(Copy No. 3)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: T. E. Peirce
Code NSEA-63R31
(Copy No. 4)

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: Library
Code 54
(Copy No. 5)

Commanding Officer and Director
David W. Taylor Naval Ship
R&D Center
Department of the Navy
Bethesda, MD 20084
Attn: Library
Code 522
(Copy No. 6)

Commanding Officer
Naval Ocean Systems Center
Department of the Navy
San Diego, CA 92152
Attn: Library
(Copy No. 7)

Defense Technical Information
Center
5010 Duke Street
Cameron Station
Alexandria, VA 22314
(Copies 8 through 19)

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: Library
(Copy No. 20)

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: V. C. D. Dawson
Code U-1
(Copy No. 21)

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: J. E. Goeller
Code WA-42
(Copy No. 22)

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: J. Baldwin
Code WA-42
(Copy No. 23)

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: J. A. Iandola
Code WA-42
(Copy No. 24)

Distribution List for UNCLASSIFIED TM 83-13 by D. R. Stinebring, M. L. Billet and J. W. Holl, dated 7 February 1983 [continuation]

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: H. K. Steves
Code WA-42
(Copy No. 25)

Commander
Naval Surface Weapons Center
White Oak Laboratory
Department of the Navy
Silver Spring, MD 20910
Attn: C. W. Smith
Code WA-42
(Copy No. 26)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: J. W. Holl
(Copies 27 through 32)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: M. L. Billet
(Copy No. 33)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: W. R. Hall
(Copy No. 34)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: D. R. Stinebring
(Copy No. 35)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: R. E. Henderson
(Copy No. 36)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: F. E. Smith
(Copy No. 37)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: D. E. Thompson
(Copy No. 38)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: A. L. Treaster
(Copy No. 39)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: B. R. Parkin
(Copy No. 40)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: Garfield Thomas Water
Tunnel Files
(Copy No. 41)

END

FILMED

9-83

DTIC